

ENVIRONMENTAL CLEAN-UP SYSTEM

Aldon R. Reinhardt

FIELD OF THE INVENTION

[0001] The present invention relates to an environmental clean-up system. More specifically, the present invention relates to an efficient system for removing contaminants from soil.

BACKGROUND OF THE INVENTION

[0002] Soil pollution is becoming a significant problem in this country. In numerous locations around the country, hazardous wastes, such as MTBE's, volatile organic compounds (VOCs), poisons and other chemicals have been inadvertently released, thereby contaminating the surrounding soil. Such soil contamination can be caused, for example, by leaking underground storage tank sites (LUST sites). The hazardous waste may leak through the soil, eventually contaminating water supplies.

[0003] Cleaning up contaminated soil is both difficult and costly. Typically, the owner of a site containing contaminated soil is responsible for this soil. However, because there is no cost effective manner of cleaning the soil, the owners of contaminated soil typically pay to have the soil removed and stored at a remote location. One such location is the Kettleman Hazardous Waste Landfill, located near Fresno, California. The cost for removing and storing contaminated soil is typically about \$65/cubic yard.

[0004] It would therefore be desirable to have a cost efficient method and apparatus for cleaning contaminated soil. It would further be desirable if this method and apparatus were portable, such that contaminated soil could

be de-contaminated on-site, without requiring that the contaminated soil be transported a significant distance.

#### SUMMARY

[0005] Accordingly, the present invention provides an efficient high-temperature water vapor generator, which is used to de-contaminate soil. The vapor generator includes a generally cylindrical combustion chamber and a surrounding structure, wherein a cavity is located between the combustion chamber and the surrounding structure. Water is routed through the cavity and into the combustion chamber, where water vapor and heat are generated in the presence of fuel, ignition and air. The heat generated inside the combustion chamber causes the water in the cavity to pre-heat. As a result, the water that is introduced to the combustion chamber is pre-heated, thereby improving the efficiency of the water vapor generator.

[0006] The high-temperature water vapor is forced into a vapor tube, which includes openings for emitting the vapor. The vapor heats the heating the vapor tube to temperatures of 600°F or greater. In one embodiment, the vapor tube is mounted in a horizontal configuration over a fixed platform.

[0007] A cylindrical soil tube is supported such that this soil tube surrounds the vapor tube. Contaminated soil is introduced to a first end of the soil tube. The soil tube is rotated along its central axis by a drive assembly. Lifting paddles are located on the inner surface of the soil tube, thereby lifting the contaminated soil into contact with the vapor tube. The soil is decontaminated by coming into contact with the high temperature vapor tube. That is, hydrocarbons in the soil are cracked by the high temperature. The lifting paddles move the soil toward the

second end of the rotating soil tube, such that decontaminated soil is expelled at the second end of the soil tube.

[0008] The decontamination process results in waste gases being emitted from within the soil tube. In one embodiment, these waste gases are routed into the vapor generator, thereby burning these waste gases and providing a more efficient system.

[0009] The soil remediation unit of the present invention is compact, and can easily be mounted on a truck bed, a trailer or a barge. Moreover, the vapor generator and drive assembly can be operated in response to one or more portable batteries, a portable fuel supply and a portable (or non-portable) water supply. Thus, the soil remediation unit can be brought to the location where the contaminated soil resides. Because the soil remediation unit decontaminates the soil on-site, there is no need to remove any contaminated soil to a remote location.

[0010] The present invention will be more fully understood in view of the following description and drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Fig. 1 is a cross sectional diagram of a vapor generator in accordance with one embodiment of the present invention.

[0012] Fig. 2 is a block diagram illustrating a vapor generating system that uses the vapor generator of Fig. 1 in accordance with one embodiment of the present invention.

[0013] Fig. 3 is a schematic side view of a soil remediation system, which uses the vapor generator system of

Fig. 2 to de-contaminate soil in accordance with one embodiment of the present invention.

[0014] Fig. 4 is a schematic top view of the soil remediation system of Fig. 3 in accordance with one embodiment of the present inventions.

[0015] Fig. 5 is an end view of a portion of the soil remediation system of Fig. 3 in accordance with one embodiment of the present invention.

#### DETAILED DESCRIPTION

[0016] Fig. 1 is a cross sectional diagram that illustrates a vapor generator 100 in accordance with one embodiment of the present invention. Vapor generator 100 is illustrated with an X-Y-Z coordinate system, as illustrated. Vapor generator 100 is generally cylindrical in nature, with the central axis of the cylinder parallel with the Z-axis.

[0017] Vapor generator 100 includes outer cylindrical section 101, inner cylindrical section 102, a pair of inner conical structures 103-104, a pair of outer conical structures 105-106, an air coupling element 107, a vapor coupling element 108, an ignition coupling element 111, a fuel coupling element 112, vapor baffle element 113, and water coupling elements 120-123.

[0018] In the described embodiment, the elements of vapor generator 100 are made of 304-stainless steel. However, it is understood that vapor generator 100 can be made of other materials in other embodiments. In the described embodiment, vapor generator 100 has a height (H0) of about 43 ¼ inches. Outer cylindrical section 101 is a tube having an outside diameter of six inches and a height (H1) of 32 inches. The walls of outer cylindrical section 101 have a thickness of 0.120 inches. Outer conical element 105 is

connected to the upper end of outer cylindrical section 101, and outer conical element 106 is connected to the lower end of outer cylindrical section. The ends of outer conical elements 105-106 that are connected to the ends of outer cylindrical section 101 have outside diameters equal to 6 inches. The walls of outer conical elements have a thickness of 0.120 inches. Thus, the ends of outer conical elements 105-106 have the same dimensions as the ends of outer cylindrical section 101. In accordance with one embodiment, the outer conical elements 105-106 are connected to the ends of outer cylindrical section 101 by a conventional welding process. Each of the outer conical elements 105-106 tapers down from a maximum diameter of 6 inches to a minimum diameter of 4 inches. Each of the outer conical elements 105-106 has a height (H4) of about 4 inches along the Z-axis.

[0019] Inner cylindrical section 102 is a pipe having an outside diameter of  $5 \frac{9}{16}$  inches and a height (H2) of 30 inches. The walls of outer cylindrical section 101 have a thickness of 0.40 inches. Inner conical element 103 is connected to the upper end of inner cylindrical section 102, and inner conical element 104 is connected to the lower end of inner cylindrical section 102. The ends of inner conical elements 103-104 that are connected to the ends of inner cylindrical section 102 have outside diameters equal to 5 inches. The walls of inner conical elements 103-104 have a thickness of 0.40 inches. Thus, the ends of inner conical elements 103-104 have the same dimensions as the ends of inner cylindrical section 102. In accordance with one embodiment, the inner conical elements 103-104 are connected to the ends of inner cylindrical section 102 by a conventional welding process. Each of the inner conical

elements 103-104 tapers down from a maximum diameter of 5 inches to a minimum diameter of 3 inches. Each of the inner conical elements 103-104 has a height (H3) of about 5 inches along the Z-axis.

[0020] The smaller ends of inner conical element 103 and outer conical element 105 are connected to air coupling element 107. In the described embodiment, the smaller ends of inner conical element 103 and outer conical element 105 are welded to the underside of the cylindrical air coupling element 107, such that these conical elements are concentrically located around a central axis (which is parallel with the Z-axis). In the described embodiment, air coupling element 107 is a cylindrical element having an inside diameter of 3 inches, an outside diameter of 4.5 inches, and a height (H5) of about 1 5/8 inches. As described in more detail below, the opening of air coupling element 107 is subsequently configured to receive an inflow of air.

[0021] Vapor baffle 113 is also connected to the lower surface of air coupling element 107. In the described embodiment, vapor baffle 113 is a pipe having an inside diameter of 3 inches, a wall thickness of about 0.118 inches, and a height (H8) of about 4 inches (along the Z-axis). The bottom edge of this pipe has a flange that extends outward from the central axis of the pipe. In the described embodiment, this flange has an outer diameter of about 5 inches. As described in more detail below, vapor baffle 113 regulates the flow of gasses within vapor generator 100.

[0022] The smaller ends of inner conical element 104 and outer conical element 106 are connected to vapor coupling element 108 in the same manner that inner conical element

103 and outer conical element 105 are connected to air coupling element 107. In the described embodiment, vapor coupling element 108 is identical to air coupling element 107. As described in more detail below, the opening of vapor coupling element 108 is subsequently configured to provide an outflow of heated water vapor.

[0023] A cavity 131 is formed between the inner conical elements 103-104/inner cylindrical element 102 and the outer conical elements 105-106/outer cylindrical element 101. As described in more detail, this cavity 131 is used to store (and pre-heat) water during normal operating conditions of vapor generator 100. Cavity 131 is capable of storing approximately 200 gallons of water.

[0024] A combustion chamber 130 is defined by inner conical elements 103-104, inner cylindrical element 102, air coupling element 107 and vapor coupling element 108. As described in more detail below, a fuel/air mixture is ignited in the combustion chamber 130, thereby heating water that has been injected into the combustion chamber 130.

[0025] Ignition coupling element 111 is a cylindrical element that extends through inner and outer conical elements 103 and 105, as illustrated. In the described embodiment, ignition coupling element 111 has an outside diameter of 1 inch, an inside diameter of 14 mm, and a length of 1 1/8 inches. The cylindrical opening through ignition coupling element 111 is threaded for receiving an ignition element (e.g., a spark plug). As described in more detail below, the ignition element introduces sparking within combustion chamber 130. The opening of ignition coupling element 111 is located about 2 inches below the lower surface of air coupling element 107.

[0026] Fuel coupling element 112 is also a cylindrical element that extends through inner and outer conical elements 103 and 105, as illustrated. In the described embodiment, fuel coupling element 112 has an outside diameter of  $3/8$  inches, an inside diameter of  $5/16$  inches and a length of about  $1\frac{1}{4}$  inches. The cylindrical opening through fuel coupling element 112 is configured to receive a fuel line. The opening of fuel coupling element 112 is located about 2 inches below the lower surface of air coupling element 107. As described in more detail below, a fuel, such as propane or natural gas, is introduced to combustion chamber 130 via fuel coupling element 112. This fuel is ignited by sparks provided by the ignition element. As described in more detail below, vapor baffle 113 helps to contain the fuel in the same general vicinity as the ignition element, thereby improving the burn of the fuel.

[0027] Water coupling elements 120-123 are also cylindrical elements. In the described embodiment, these elements 120-123 each have an outer diameter of 1 inch, an inner diameter of  $\frac{1}{2}$  inches. Water coupling element 120, which has a length of about  $1\frac{1}{4}$  inches, extends through both outer cylindrical section 101 and inner cylindrical section 102. As described in more detail below, water coupling element 120 is configured to receive a water injection device, such that water can be injected into inner chamber 130. Water coupling elements 121-123, each of which has a length of about  $1\frac{1}{4}$  inches, extends through outer cylindrical section 101 (but not through inner cylindrical section 102). The central axes of water coupling elements 121-122 are located at a height (H6) of about  $1\frac{1}{4}$  inches above the lower edge of outer cylindrical section 101. The central axes of water coupling elements 120 and 123 are located at a



distance (H7) of about 2½ inches below the upper edge of outer cylindrical section 101.

[0028] As described in more detail below, water is introduced into cavity 131 via one or both of water coupling elements 121 and 122. The water level in cavity 131 is maintained at a level that is higher than water coupling element 123. As described in more detail below, water is removed from cavity 131 via water coupling element 123.

[0029] Although vapor generator 100 has been described with particular dimensions and shapes, it is understood that other dimensions and shapes can be used in other embodiments.

[0030] Fig. 2 is a block diagram illustrating a vapor generating system 200 that uses vapor generator 100 in accordance with one embodiment of the present invention. In addition to vapor generator 100, system 200 includes air supply line 201, blower 202, ignition element 211, ignition controller 212, fuel supply line 221, fuel supply 222, water supply line 231, water supply 232, water injector 233, pre-heated water supply line 234, water plug 235 and vapor exhaust line 241.

[0031] In general, system 200 operates as follows to produce high temperature steam (vapor). As described in more detail below, this high temperature vapor is subsequently used to decontaminate a material, such as soil. Air, water, fuel and sparks are introduced to vapor generator 100 by air blower 202, water injector 233, fuel supply 222 and ignition element 211, respectively. The sparks ignite the fuel and air to heat the injected water. In response, vapor generator 100 generates super-heated steam (vapor) having a temperature of about 400 to 1000°F. The high temperature water vapor is forced out through vapor

exhaust line 241. As described in more detail below, exhaust line 241 carries the high temperature water vapor to a soil moving device. The high temperature water vapor is then used to remove contaminants from soil that is forced through the soil moving device.

[0032] In the described embodiment, air supply line 201 is flexible aluminum tubing having an inside diameter of 3 inches and a length of about 20 inches. Air supply line 201 can be coupled to air coupling element by a clamp. When air blower 202 is turned on, air is forced through air supply line 201 and into combustion chamber 130. In the described embodiment, air blower 202 is a 10 horsepower (hp) high-speed hydraulic motor available from Spencer Industries, as part number EAT104-1006-006. This hydraulic motor is capable of operating at about 2000 rpm in response to a 24 Volt supply battery. In the described embodiment, air blower 202 provides an air flow in the range of about 200 to 700 cubic feet per minute (cfpm) at a maximum pressure in the range of about 2 to 5 pounds/square inch (psi).

[0033] In the described embodiment, both fuel coupling element 112 and fuel supply line 221 have an inside diameter of about 3/8 inch. Fuel supply line 221, which is made of stainless steel, is coupled to fuel coupling element with a conventional metal sealed connector. Fuel supply 222 is controlled to provide a flow of fuel through fuel supply line 221 and fuel coupling element 112 into combustion chamber 130. In the described embodiment, the fuel supply 222 is a 100-gallon fuel tank containing either propane or natural gas. Fuel supply 222 can be controlled manually or automatically in various embodiments of the present invention. The maximum fuel flow into combustion chamber 130 is on the order of 40 to 80 standard cubic feet per hour

(scfh). In one embodiment, the fuel flow is about 2 gallons per hour, for a daily (8 hour) fuel cost of about \$20. In the described embodiment, a control valve is inserted into fuel coupling element 112, thereby limiting the fuel pressure to about 8 psi.

[0034] In the described embodiment, ignition element 211 is located at the same height as fuel coupling element 112, with a 180 degree separation between ignition element 211 and fuel coupling element 112. Ignition element 211 can be, for example, a spark plug available from Bosch as part number W6DC. Other spark plugs can be used in other embodiments. Ignition controller 212 transmits electrical control signals to ignition element 211. These electrical control signals are selected such that ignition element 211 fires (sparks) continuously while these electric control signals are being transmitted. The electrodes of ignition element 211 are located inside of combustion chamber 130, such that the sparks are created within combustion chamber 130. The expected life of ignition element 211 under these conditions is on the order of about 5000 hours. In the described embodiment, ignition controller 212 is a spark generator available from Dongan Electric Manufacturing Company as part number A06SAG. Ignition controller 212 is capable of operating in response to a 24 Volt battery supply.

[0035] Water supply line 231 couples water supply 232 to water coupling element 121. In the described embodiment, water supply line 231 is a rubber hose having an inside diameter of about 1 inch. In one embodiment, a 3/8 inch Nupro ball valve is included in water coupling element 121. Water supply line 231 is coupled to water coupling element 121 by a 1/2 inch pipe nipple. In one embodiment, water

supply 232 is supplied by a water pump, available from Shurflo as part number 52063-B979. In the described embodiment, water coupling element 122 is sealed by plug 235. In this embodiment water coupling element 122 provides redundancy, in case water coupling element 121 is (or becomes) defective. In an alternate embodiment, water supply 232 can be coupled to both water coupling elements 121 and 122.

[0036] Water from water supply 232 flows into cavity 131. The water level 226 within cavity 131 is controlled such that this water level 226 is higher than water coupling element 123. In a particular embodiment, water level 226 is controlled such that cavity 131 is substantially full during normal operation of system 200.

[0037] The water in cavity 131 is heated due to the proximity to combustion chamber 130. That is, heat from the combustion chamber 130 heats the water in cavity 131 via the thermally conductive inner cylindrical section 102 and inner conical structures 103-104. In one embodiment, the water in cavity 131 is heated to a temperature of about 60 to 212°F. Water supply 232 forces the heated water to exit cavity 131 and enter pre-heated water supply line 234. From pre-heated water supply line 234, the heated water enters water injection element 233. In response, water injection element 233 causes the heated water to enter combustion chamber 130 as a spray. In the described embodiment, water injection element 233 injects water at a rate of 2 to 5 gallons/minute (gpm). Water injection element 233 can be, for example, part number 137-155, available from Delaven.

[0038] Within combustion chamber 130, the sparks introduced by ignition element 211 ignite the fuel introduced by fuel supply 222 and the air introduced by

blower 202, thereby generating heat, which in turn, causes the pre-heated water introduced by water injection element 233 to become super-heated. Air blower 202 forces the burnt fuel/water mixture (hereinafter referred to as the "vapor") toward the bottom of combustion chamber 130. The vapor pressure is increased as the combustion chamber 130 narrows.

[0039] Locating ignition element 211 and fuel coupling element 221 near the top of the combustion chamber 130 advantageously allows a long time for the fuel to burn. That is, the fuel is allowed to burn down the entire length of the combustion chamber 130. This allows the fuel to burn completely. The length of the combustion chamber 130 is selected to be long enough to allow the fuel to burn completely.

[0040] The force introduced by air blower 202 further causes the vapor to flow through vapor supply line 241. The vapor in vapor supply line 241 has a temperature in the range of about 200 to 1400°F and a pressure in the range of about  $\frac{1}{2}$  to 5 psi. In none embodiment, vapor supply line 241 is stainless steel tubing, having a diameter of about 2 inches. The exhaust provided at vapor supply line 241 is relatively clean. It is estimated that the vapor will consist of about 20 water vapor 5% CO, 10% O<sub>2</sub>, 63% CO<sub>2</sub> and 2% NO.

[0041] In accordance with one embodiment, system 200 is started as follows. First, air blower 202 and ignition controller 212 are turned on. As a result, any residual fuel in combustion chamber 130 will be safely burnt and blown out of vapor supply line 241. About ten seconds later, fuel supply 222 is turned on, thereby providing fuel flow to combustion chamber 130. At this time, fuel begins burning, thereby pre-heating combustion chamber 130. About

ten seconds after fuel supply 222 is turned on, water supply 232 is turned on, thereby introducing water to combustion chamber 130. Vapor is then generated in combustion chamber 130 in the manner described above.

[0042] In accordance with another embodiment, system 200 is turned off by turning off fuel supply 222, ignition controller 212 and water supply 232 at about the same time. Blower 202 is allowed to run for about 30 seconds longer, thereby clearing combustion chamber 130 and vapor supply line 241.

[0043] Fig. 3 is a schematic side view of a soil remediation system 300, which uses vapor generator system 200 to de-contaminate soil in accordance with one embodiment of the present invention. Fig. 4 is a schematic top view of soil remediation system 300. Note that vapor generator system 200 is not shown in Fig. 4 for reasons of clarity. Soil remediation system 300 includes a base assembly 301, which is formed from steel. In the described embodiment, base assembly 301 has a height of about 4 inches, a length of about 276 inches and a width of about 40 inches. Base assembly 301 is supported by ten support legs, including support legs 302-306. Note that five support legs (not shown) are hidden behind support legs 302-306 in the side view of Fig. 3. Each support leg is made of steel. In the described embodiment, each of the support legs has a height of about 18 inches and a square cross section of about 4 inches by 4 inches. The support legs are welded to base assembly 301.

[0044] The support legs are also welded to an underlying platform 307. In the described embodiment, platform 307 is the bed of a large truck or trailer. In the described embodiment, platform 307 is supported by four or more wheels

of the truck/trailer, including wheels 308-309, by conventional means. Note that two wheels (not shown) are hidden behind wheels 308-309 in the side view of Fig. 3. In other embodiments, platform 307 can be a raised stationary structure.

[0045] System 300 further includes a front support assembly 311 and a rear support assembly 312, each having an L-shaped cross section. The bases of front and rear support assemblies 311-312 are bolted down to base assembly 301. In the described embodiment, front and rear support assemblies 311-312 are made of steel having a thickness of about 1 inch. The bases of front and rear support assemblies 311-312 each have a length of about 8 inches and a width of about 36 inches. Front support assembly 311 has a height of about  $57\frac{1}{2}$  inches, and rear support assembly 312 has a height of about 31 inches. An inner tube rear support 314 is welded to rear support assembly 312 as illustrated. Inner tube rear support 314 is a cylindrical steel tube having a length of about 18 inches, and an outside diameter of about  $3\frac{1}{2}$  inches.

[0046] A vapor tube 313 extends between, and is supported by, front and rear support assemblies 311-312. A first end of vapor tube 313 extends through an opening in front support assembly 311. In one embodiment, the first end of vapor tube 313 is welded in this opening. The first end of vapor tube 313 is open. As described in more detail below, this opening in vapor tube 313 is coupled to receive the high temperature vapor provided by vapor generator 100.

[0047] The second end of vapor tube 313 fitted over inner tube support assembly 314, as illustrated. As a result, inner tube support assembly 314 supports the second end of vapor tube 313. The second end of vapor tube 313 is welded

to rear support assembly 312. As a result, the second end of vapor tube 313 is effectively sealed. In the described embodiment, vapor tube 313 is schedule 40 type 347 stainless steel cylindrical tube, having a 4 inch outside diameter, a wall thickness of 0.237 inches, and a length of 216  $\frac{1}{4}$  inches. In other embodiments, vapor tube 313 can have other shapes. For example, vapor tube 313 can have a triangular cross section, with a vertex of the vapor tube pointing straight up.

[0048] A plurality of vapor openings 315 extend through a sidewall of vapor tube 313. These vapor openings 315 are located along the length of vapor tube 313. In a particular embodiment, these vapor openings 315 are all located along a straight line that extends along the length of vapor tube 313. Vapor tube 313 is positioned such that these vapor openings 315 are located on the underside of vapor tube 313. In the described embodiment, there are about 29 vapor openings located on the underside of vapor tube 313, each having a diameter of about  $\frac{3}{8}$  inches. As described in more detail below, the high temperature vapor from vapor generating system 200 enters the first end of vapor tube 313 and exits through vapor openings 315. The high temperature vapor heats vapor tube 313 to a temperature that is sufficiently high to remove contaminants from soil.

[0049] A drive assembly 331 and an idler assembly 332 are also mounted on base assembly 301. Drive assembly 331 and idler assembly 332 support a main auger assembly 320, which surrounds, but does not contact, vapor tube 313. Main auger assembly 320 includes wear cylinders 321-322, gear element 323, soil tube 324, and internally located lift paddles 1-4. In the described embodiment, soil tube 324 is a schedule 40 C/S pipe having an outside diameter of 20 inches and a



length of 216 inches. In other embodiments, soil tube 324 can have other dimensions. For example, soil tubes having diameters of 30 or 40 inches can be used to provide more soil throughput. The location of soil tube 324 is maintained by gear element 323, which engages a corresponding gear element 333 on drive assembly 331. Soil tube 324 is positioned such that a  $\frac{1}{2}$  inch clearance is maintained between a first end of soil tube 324 and front support assembly 311.

[0050] During normal operation, soil tube 324 is rotated along its central axis, around the stationary vapor tube 313. This rotation is facilitated by drive assembly 331, idler assembly 332 and motor 337. As shown in Fig. 4, drive assembly 331 includes a rotating drive element 335 and a rotating support element 336. Rotating drive element 335 includes two wear rings 401-402, which contact wear ring 321, and a recessed gear element 333, which engages raised gear element 323. Rotating support element 336 includes wear rings 411-412, which contact wear ring 321, and a recessed channel 413, which is located between wear rings 411-412. Recessed channel 413 receives, but does not contact gear element 323. In the described embodiment, wear rings 401-402 and 411-412 are made of the same material as wear ring 323.

[0051] Idler assembly 332 includes a first rotating idler assembly 421 and a second rotating idler assembly 422. The first rotating idler assembly 422 includes a first rotating wear ring 431, which contacts wear ring 322. The second rotating idler assembly 422 includes a second rotating wear ring 432, which contacts wear ring 322. The first and second rotating wear rings 431-432 rotate about a pair of

corresponding axles, which are supported by a corresponding pair of brackets, which are connected to base assembly 301.

[0052] Fig. 5 is an end view of wear ring 321, gear element 323 and drive assembly 331. Note that gear element 323 extends above wear ring 321. In the described embodiment, gear element 323 has a height of 24 inches and a width of 1 1/8 inches. In the described embodiment, gear element 323 is formed by one or more laser cut pieces of A36 steel, which are welded to wear ring 321. As described above, gear element 333 is slightly recessed with respect to wear rings 401-402, such that gear element 333 engages with gear element 323, and wear rings 401-402 contact wear ring 321. Also, as described above, wear rings 411-412 contact wear ring 321, but gear 323 does not contact assembly 201 within channel 413. Both rotating drive element 335 and rotating support element 336 are suspended by axles that are supported by brackets that are mounted on base assembly 301. Both rotating drive element 335 and rotating support element 336 are free to rotate about their central axes. The drive shaft of motor 337 is attached to a coupling element 334, thereby enabling motor 337 to turn rotating drive element 335 of drive assembly 331. Rotating drive element 335 thereby rotates main auger assembly 320 via gear elements 333 and 323. In the described embodiment, motor 337 is a 10 hp hydraulic motor capable of turning main auger assembly 320 at a rate of 0-10 rotations per minute (rpm). In the described example, motor 337 is part number EAT104-1006-006, available from Spencer Industries.

[0053] Idler assembly 332 supports main auger assembly 301 as the main auger assembly is rotated. More specifically, wear ring 322 rotates on first rotating wear ring 431 and second rotating wear ring 432. In the

described embodiment, each of wear rings 431-432 has an outside diameter of 21 inches. Wear ring 322 rests on wear rings 431-432. Wear ring 322 rotates freely on wear rings 431-432, thereby enabling the entire auger assembly 320 to rotate in response to motor 337. Wear rings 321-322 and 431-432 are made of a material that is more resistant to wear than soil tube 324. For example, wear rings 321-322 and 431-432 can be made of A36 steel having a thickness of  $\frac{1}{2}$  inch.

[0054] A soil feed chute 341 is attached to front support element 311. Chute 341 includes an upper opening for receiving contaminated soil, and a lower opening for feeding contaminated soil through front support element 311 into tube 324. The contaminated soil can be loaded into the upper opening of chute 341 in a controlled manner by various means, including a conveyor belt 351.

[0055] A set of four lifting paddles 1-4 are located inside soil tube 324. The ends of these lifting paddles 1-4 are shown in Fig. 5. Lifting paddles 1-4 have angled ends, which help to hold soil as the soil tube is rotated. The direction of rotation, R, is illustrated in Fig. 5. Lifting paddles 1-4 each follow a spiral pattern along the length of soil tube 324. This spiral pattern is shown schematically by line 325 in Fig. 3. Note that the lifting paddles maintain a spacing of about 90 degrees throughout this spiral pattern. This spiral pattern helps to move soil from the first end of soil tube 324 to the second end of soil tube 324, as soil tube 324 is rotated. Lifting paddles 1-4 also cause the contaminated soil to be lifted over, and then dropped down upon, vapor tube 313. As a result, the soil does not clog the vapor openings 315 in vapor tube 313. As described in more detail below, vapor tube 313 is heated to

a temperature of about 500 to 1200°F by vapor produced by vapor generator 100. When the contaminated soil comes into contact with vapor tube 313, the hydrocarbons and volatile organic compounds (VOC's) present in the contaminated soil are cracked, thereby eliminating the hydrocarbons, and providing one or more by-product gasses (CO and CO<sub>2</sub>). The high temperature vapor tube 313 also eliminates other contaminants from the soil, such as mercury.

[0056] Decontaminated soil exits the second end of soil tube 324, and falls through exit chute 342, which extends through base assembly 301 and platform 307. The decontaminated soil can then be removed, for example, by a conveyor belt assembly 352.

[0057] In accordance with one embodiment, a cover 360 extends over main auger assembly 320, as illustrated in Fig. 3. This cover 360 is used to collect the gases that are expelled from soil tube 324. These gases include water vapor that is expelled through the holes 315 in the bottom of vapor tube 313. These gases also include the by-product gases created by decontaminating the soil. The air supply line 201 of vapor generator 100 is attached to cover 360, such that air blower 202 pulls in air present under cover 360. As a result, remaining contaminants in the by-product gases are burned when returned to vapor generator 100.

[0058] In the foregoing manner, the soil remediation system 300 is capable of efficiently cleaning contaminated soil. Soil remediation system 300 can easily be moved to job sites, thereby eliminating the need to transport contaminated soil over long distances. Soil remediation system 300 can advantageously be run in remote locations, because the motor 337, blower 202, ignition control unit 212 all run from battery power, fuel supply 222 can be provided

in portable tanks, and water is either readily available or can be provided by portable tanks.

[0059] The various embodiments of the structures and methods of this invention that are described above are illustrative only of the principles of this invention and are not intended to limit the scope of the invention to the particular embodiments described. For example, although soil tube 324 has been described as having a horizontal arrangement, it is understood that one end of soil tube 324 may be elevated with respect to the other end. Thus, the invention is limited only by the following claims.